# SINGLE SPEED TURBINE GENERATOR FOR DIFFERENT POWER SYSTEM OUTPUT FREQUENCIES IN POWER GENERATION SYSTEMS AND ASSOCIATED METHODS

## Field of The Invention

This invention is related to the power generation industry and, more particularly, to the field of turbine generators and related methods.

## Background of the Invention

Within the power generation industry, large-scale power generators convert mechanical energy, typically the energy output of a turbine, into electrical energy. The basic components of such power generators are a frame-supported stator core that provides a high permeability path for magnetism and a rotor assembly positioned to rotate continuously within the stator core so as to induce electrical current through rotor-borne conductors moving through magnetic fields set up within the stator. The resulting current is carried by high-current conductors through and out from a housing surrounding the power generator, to connectors that provide the current to a plant bus for power distribution to consumers, commercial establishments, and other users of electrical power.

It is common in the power generation industry to use 50 Hertz (Hz) or 60 Hz gas or steam turbines, e.g., using air or steam cooling, in power plants for different applications and particular for efficiency and power output issues. These 50 Hz and 60 Hz designs are often

used in simple cycle power plants and in combined cycle power plants to provide higher levels for efficiency and power output. A simple cycle power plant, for example, is one where a gas turbine which drives a generator is the sole source of power generation. A combined cycle power plant, for example, uses gas turbine exhaust to create steam which is utilized by a steam turbine.

Separate frequencies, e.g., 50 Hz versus 60 Hz, often require separate components for each frequency. This can require additional manufacturing constraints, require additional inventory, and require an increase in changeover costs. To reduce product cost, it is desirable to reduce the number of parts produced so that the larger volumes of those parts produced can result in lower part cost and reduced tooling investment.

With 50 Hz and 60 Hz synchronous applications, the turbine is usually required to operate at the delivery current Hz, e.g., at 3000 revolutions per minute (rpm) or 50 revolutions per second (rps) for two-pole 50 Hz applications and 3600 rpm or 60 rps for two-pole 60 Hz applications. If the turbine is rotated at a frequency other than synchronous, e.g., due to frequency variations, the blades in a turbine element, e.g., a low pressure turbine element, may resonate at their natural frequency. Blading mechanical fatigue can then result with subsequent damage and failure. Such problems can be expensive and time consuming to repair and can cost down time for the power generation system.

## Summary of the Invention

In view of the foregoing, the present invention advantageously provides a single speed turbine generator that can be used in different power system output frequencies, e.g., either 50 Hz or 60 Hz, applications of a power generation system for power plants. The present

invention also advantageously provides a power generation system and associated methods that allow the same turbine and generator to be used in both 50 Hz and 60 Hz applications. Because a turbine system, e.g., a turbine or a turbine with a gear box (hereinafter "a turbine"), and a generator rotor always rotate at substantially the same speed according to the present invention, variations in system frequency appear as variations in the generator rotor alternating current frequency so that the turbine still operates at the same frequency as the generator rotor even though variations in the system frequency may occur. Hence, in view of this, the present invention additionally advantageously provides a power generation system and associated methods that allows enhanced turbine design. The present invention further advantageously provides a power generation system, a power generator, and associated methods that have enhanced stability characteristics.

More particularly, a power generation system, to compensate for different power system output frequencies according to the present invention, preferably includes a turbine having a turbine rotor positioned to rotate at a preselected rotational frequency and a generator positioned to generate a power system electrical output current at a preselected power system output frequency. The generator preferably has a generator stator and a generator rotor positioned within the generator stator to induce electromotive force to the generator stator. The generator rotor preferably is coupled to the turbine rotor to be driven by the turbine rotor at substantially the same preselected rotational frequency. The generator rotor preferably has a rotor body and a plurality of generator coils mounted to the rotor body to induce electromotive force to the generator stator during rotation. The power generation system also preferably

includes a frequency differentiator coupled to the generator rotor and connected to the power system electrical current output to differentiate between the preselected power system output frequency and the preselected rotational frequency of the generator rotor so that variations in the preselected power system frequency appear as variations in the generator rotor alternating electrical current frequency to thereby compensate for different preselected power system output frequencies.

According to the present invention, the frequency differentiator can advantageously be provided by an exciter or other frequency differentiation systems, such as an electronic cyclo-converter or other AC to AC, DC to AC, or AC to DC converter, as will be understood by those skilled in the art. An exciter, for example, of the present invention preferably has an exciter rotor coupled to the generator rotor to provide a magnitomotive force to the generator rotor during rotation at the same preselected rotational speed. The exciter rotor preferably has a rotating armature including at least one coil positioned thereon, and more preferably a plurality of coils with a three-phase alternating current field winding. The frequency differentiator also preferably includes an alternating current regulator positioned to receive unregulated electrical current from the power system electrical output current at the preselected power system output frequency and positioned to supply a regulated alternating current to one or more coils of the rotating armature of the exciter so that the electrical frequency of the one or more coils of the rotating armature substantially equals a difference between the preselected power system output frequency and the preselected rotational frequency. Advantageously, a portion, e.g., about 5 percent to about 20 percent, of the power system electrical current output of the power

generation system is transferred to the generator stator from the generator rotor.

The present invention further advantageously provides a method of compensating for different power system output frequencies in a power generation system. The method preferably includes selecting a desired power system output frequency for a power generation system, selecting a desired rotational frequency of a generator rotor of a generator of the power generation system, and differentiating between the selected power system output frequency and the selected rotational frequency of the generator rotor so that variations in the preselected power system output frequency appear as variations in generator rotor alternating electrical current frequency to thereby compensate for different preselected power system output frequencies. The method can also include the power generation system having an exciter coupled to the generator rotor and rotating at the same selected rotational frequency, and the step of differentiating can include regulating alternating current received from the power system alternating current output and supplying the regulated alternating current to the exciter.

The frequency difference, e.g., 5 Hz, between the frequency of the power system output and the rotational frequency of the generator rotor or exciter, for example, can then be added to or subtracted from the generator rotor frequency, e.g., 55 Hz, to thereby produce the desired power generation system output frequency, e.g., 50 Hz or 60 Hz. Because the electrical frequency of the generator rotor compensates for power system swings, the power generation system of the present invention allows for enhanced stability characteristics for different power system output frequencies.

## Brief Description of the Drawings

Some of the features, advantages, and benefits of the present invention having been stated, others will become apparent as the description proceeds when taken in conjunction with the accompanying drawings in which:

FIG. 1 is a schematic diagram of a power generation system according to the present invention;

FIG. 2 is a schematic diagram of a power generation system according to the present invention; and

FIG. 3 is a fragmentary perspective view of a rotating armature exciter, a generator rotor, and a generator stator of a power generation system according to the present invention.

## Detailed Description of Preferred Embodiments

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the illustrated embodiments set forth herein. Rather, these illustrated embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout, and prime and double prime notation, if used, indicate similar elements in alternative embodiments.

FIGS. 1-3 illustrate a power generation system **10** according to the present invention which compensates for different frequencies so that a single turbine generator **20** can be used for multiple frequency applications, e.g., both 50 Hz and 60 Hz applications. To compensate for different power system output frequencies, the power

generation system **10** preferably includes a turbine **12** having a turbine rotor **13** positioned to rotate at a preselected rotational frequency or speed, e.g., 55 revolutions per second (corresponding to 3300 revolutions per minute, or 55 Hz electrical for a 2-pole generator), and a generator **20**, e.g., a 2-pole synchronous generator with a three-phase alternating current field winding, positioned to generate a power system electrical output current at a preselected power system output frequency. The generator **20** preferably has a generator stator **22** and a generator rotor **25** positioned within the generator stator **22** to induce electromotive force to the generator stator **22**. The generator rotor **25** preferably is coupled to the turbine rotor **13** to be driven by the turbine rotor **13** at substantially the same preselected rotational frequency. The generator rotor **25** preferably has a rotor body **26** and a plurality of generator coils **28** mounted to the rotor body **26** to induce electromotive force to the generator stator **22** during rotation. The generator rotor **25** preferably includes a rotor shaft **27**, the turbine rotor **13** preferably includes a turbine shaft **14**, and the generator rotor **25** preferably is coupled to the turbine rotor **13** by coupling the rotor shaft **27** to the turbine shaft **14** (see FIG. 1). The power generation system **10** preferably also includes a frequency differentiator **30** coupled to the generator rotor **25** and connected to the power system electrical current output to differentiate between the preselected power system output frequency and the preselected rotational frequency of the generator rotor **25** so that variations in the preselected power system frequency appear as variations in the generator rotor alternating electrical current frequency to thereby

compensate for different preselected power system output frequencies. The supply to the field winding and the field winding coils preferably are oriented so that a traveling magnetic wave as illustrated (see FIG. 2) equal to the system frequency will be created in the generator core and gap.

The frequency differentiator **30** as used herein refers to taking a difference between the preselected power output frequency and the preselected rotational frequency. The frequency differentiator **30** preferably is provided by an exciter **40** having an exciter rotor **41** coupled to the generator rotor **25** to provide a magnitomotive force to the generator rotor **25**, e.g., the coils of the rotor, at the same preselected rotational frequency. The exciter rotor **41** preferably has a rotating armature **45** including at least one coil positioned thereon and preferably a plurality of exciter field windings **46, 47, 48.** The frequency differentiator **30** also preferably includes an alternating current ("AC") regulator **50** positioned to receive unregulated electrical current from the power system electrical output current at the preselected power system output frequency by a connection to each of the phases as shown (see FIG. 2). The AC regulator is also preferably positioned to supply a regulated alternating current to the at least one coil **46** of the rotating armature **45** of the exciter **40** to provide a magnitomotive force (MMF) at a frequency substantially equal to a difference between the preselected power system output frequency and the preselected rotational frequency as will be understood by those skilled in the art. If variations in the system frequency occur, then these variations show up as a slip frequency in the rotating armature **45** of the exciter **40**.

The generator stator **22** also preferably has a plurality of stator coils **23** which provide a connection for the power system electrical current output and are connected to a neutral ground or grounding device **24** as understood by those skilled in the art. A portion, e.g., equal to the difference between the rotation frequency and the system frequency or the percent slip as understood by those skilled in the art (about 5 to about 20 percent), of the power system electrical current output, i.e., alternating current, of the power generation system **10** is transferred to the generator stator **22** from the generator rotor **25** which receives it from the at least one coil **46** of the rotating armature **45** of the exciter **40**. The exciter rotating armature **45** preferably has a plurality of exciter alternating current coils or field windings, e.g., three-phase field winding, to thereby provide a plurality of alternating current phases. The exciter **40** preferably is excited at the preselected power system output frequency. As shown in FIG. 3, such an exciter **40** preferably is simple in design and would not have a collector or other rotating electronic components, e.g., diodes, as understood by those skilled in the art.

For example, the preselected frequency of the generator rotor **25** and the turbine rotor **13** can be about 55 Hertz, and the preselected power system output frequency can be either about 60 Hertz or about 50 Hertz. In such a power generation system **10** of the present invention, the generator rotor **25** and exciter **40** are each preferably larger than conventional generator rotors and exciters for a comparable system at a desired output frequency. As understood by those skilled in the art, the size of the generator rotor and exciter will be a function of the slip frequency, i.e., the larger the slip frequency

the larger the rotor and exciter. Also, the generator rotor body **26** preferably includes a plurality of rotor body lamination layers **29** to thereby define a laminated rotor (see FIG. 3). Nevertheless, as understood by those skilled in the art such laminations may not be required. Each of the plurality of rotor body lamination layers **29**, however, preferably are positioned adjacent another one of the plurality of rotor body lamination layers **29** in a stacked relationship in a plane extending tranverse to a longitudinal axis of the generator rotor shaft **27** as shown in FIG. 3. The power generation system **10** of the present invention allows the same turbine **12** and generator **20**/exciter **40** to be used for both 50 Hz and 60 Hz applications, for example. The turbine rotor **13** and the generator rotor **25** preferably always rotate at the same speed and allows enhanced turbine designs as will be understood by those skilled in the art.

As shown in FIGS. 1-3, the present invention further advantageously provides a method of compensating for different power system output frequencies in a power generation system **10**. The method preferably includes selecting a desired power system output frequency for a power generation system **10**, selecting a desired rotational frequency of a generator rotor **25** of a generator **20** of the power generation system **10**, and differentiating between the selected power system output frequency and the selected rotational frequency of the generator rotor **25** so that variations in the preselected power system output frequency appear as variations in generator rotor alternating electrical current frequency to thereby compensate for different preselected power system output frequencies. The method can also include the power

generation system **10** having an exciter **40** coupled to the generator rotor **25** and rotating at the same selected rotational frequency, and the step of differentiating can include regulating alternating current received from power system alternating current output and supplying the regulated alternating current to the exciter **40**.

The method can also include the exciter **40** having a rotating armature **45** with at least one coil **46**, and the electrical frequency of the at least one coil **46** of the rotating armature **45** substantially equaling a difference between the selected power system output frequency and the selected rotational frequency. The method can further include the generator **20** further having a generator stator **22** positioned to receive induced electromotive force from the generator rotor **25** during rotation, and a portion of the alternating electrical current output of the power generation system **10** being transferred to the generator stator **22** from the generator rotor **25** which, in turn, receives it from the exciter **40**. The selected rotational frequency of the generator rotor **25**, for example, can be about 55 Hertz, and the selected power system output frequency, for example, can be about 60 Hertz or about 50 Hertz.

Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.